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Study of extreme wet and dry periods in Cyprus using climatic indices

D. Katsanos[a,*], A. Retalis[a], F. Tymvios[b,c], S. Michaelides[c]

[a] IERSD, National Observatory of Athens, Greece
[b] Department of Meteorology, Nicosia, Cyprus
[c] The Cyprus Institute, Nicosia, Cyprus

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ABSTRACT

Climate change affects the precipitation regime globally, including its extreme values, as well as the frequency of the corresponding extreme events. Generally, observations and simulations with climate models show that a warming climate typically results in an intensification of precipitation extremes. An analysis of the daily precipitation database for the island of Cyprus is performed, using a period of 50 years. A number of climatic indices for precipitation are calculated, including the Standardized Precipitation Index (SPI), using the dense network of rain gauges of the Cyprus Department of Meteorology. All parameters are calculated for the recent 30-year period 1981–2010 (considered by the World Meteorological Organization as the new current standard period); the results are compared with those of the period 1961–1990 (considered by the World Meteorological Organization as the reference period), with a view to examine the differences in the occurrence of wet and dry periods. The results show an increase in the occurrence of heavy rainfall events and a slight decrease in extreme drought events.

1. Introduction

Precipitation is one of the most important factors of Earth's water cycle, affecting a number of human activities, like agriculture, with significant impacts in the economy. Extreme events like flash floods or prolonged droughts influence the lives of many people on the global and regional scales. The study of the trends in precipitation is crucial in order to decide short-term or long-term measures, regarding water resources management. Hence, the knowledge of the spatio-temporal and physical characteristics of rainfall by all available means is essential (Michaelides et al., 2009a).

The Mediterranean region is characterized by its vulnerability to climatic extremes. Studies over the Mediterranean basin show that even though the amounts of precipitation decrease, the events of extreme rainfall have a tendency to increase (Alpert et al., 2002). Focusing over the Eastern Mediterranean, Nastos and Zerefos (2009) found an increase in the occurrence of consecutive dry days, especially in the Aegean Sea, and a decrease in the incidence of consecutive wet days over the same area. Accordingly, Federico et al. (2009) showed a negative trend in yearly precipitation using the Standardized Precipitation Index (SPI), with local exceptions, for the region of Calabria in Southeastern Italy. Livada and Assimakopoulos (2007) calculated the SPI to detect drought events on a spatial and temporal basis, built on monthly precipitation data from 23 stations in Greece, for the period 1950–2000. They concluded that mild and moderate droughts reduce from north to south and from west to east on the 3- and 6-month time scale, while the frequency of occurrence of severe and extreme drought conditions is very low over the whole Greek territory on the 12-month running time scale. Michaelides and Pashiardis (2008) studied drought in Cyprus by calculating SPI, based on precipitation records of the network of the Cyprus Department of Meteorology, for the hydrological year 2007–2008 for different time scales, quantifying, thus, the precipitation deficit during different months of the year.

The climate of Cyprus is typical Mediterranean, exhibiting hot dry summers from mid-May to mid-September and rainy, rather variable, winters from November to mid-March (Cyprus Department of Meteorology, 2016). With regard to Köppen–Geiger classification codes (see Kottek et al., 2006), Cyprus can be classified as belonging to the two types Csa = Warm temperate (summer dry – hot summer) and Csb = Warm temperate (summer dry – warm summer).

Michaelides et al. (2009b) showed a tendency for reduced probability of large annual rainfall amounts, which reflected in a severe water shortage on the island; this in turn has resulted in an acute problem for the economy, in conjunction with the increasing water demands.

In a study by Anagnostopoulou and Tolika (2012), the authors proposed a value of around 40–45 mm in daily precipitation, in order to characterize an event as extreme, in the island of Cyprus. In the present

* Corresponding author.
E-mail address: katsanos@noa.gr (D. Katsanos).

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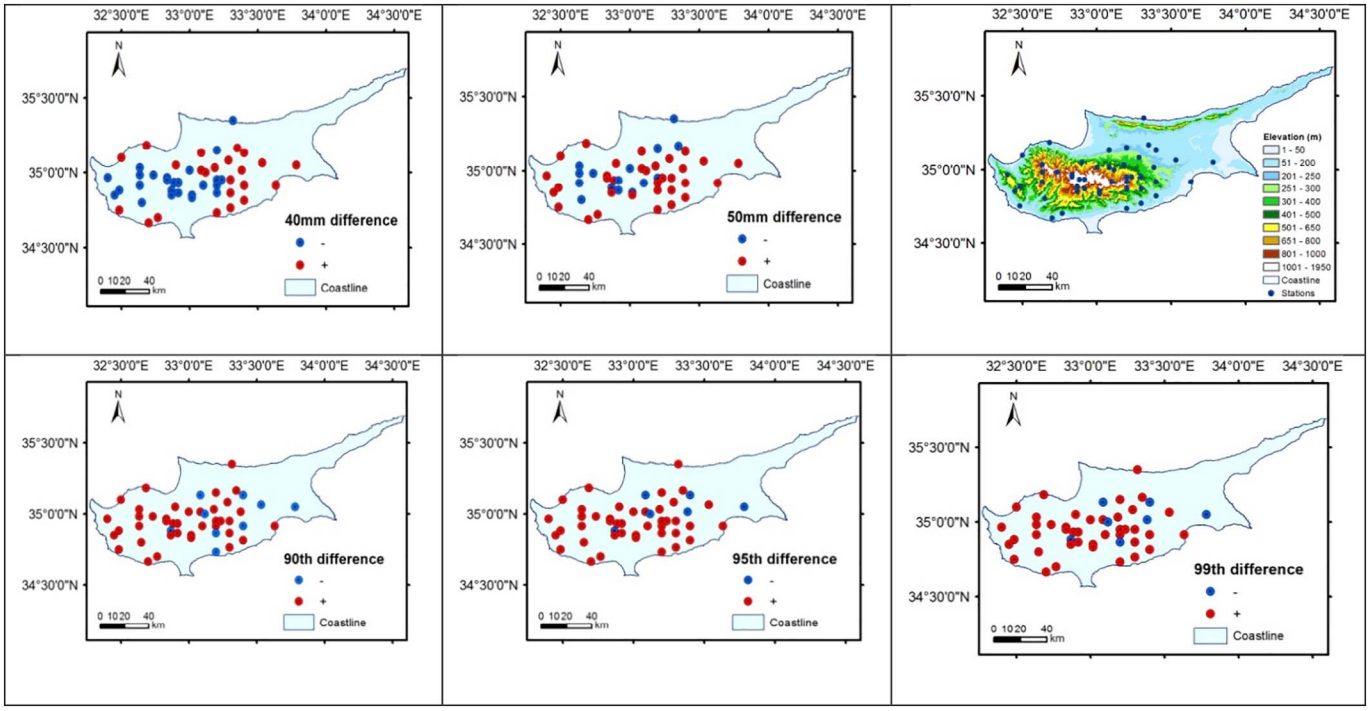

Fig. 1. Trends in the precipitation indices used: R40mm (upper left), R50mm (upper middle), 90th (lower left), 95th (lower middle) and 99th (lower left) percentiles; for positive trends, stations are shown as red; for negative trends stations are shown as blue. The map in the upper right shows the land relief with the positions of the stations used in this study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Classification of a wet/dry period based on SPI values.

Value	Drought class	Probability
SPI > 2.0	Extremely wet	0.023
1.5 < SPI ≤ 2.0	Very wet	0.044
1.0 < SPI ≤ 1.5	Moderately wet	0.092
−1.0 ≤ SPI ≤ 1.0	Near normal	0.682
−1.5 ≤ SPI < −1.0	Moderate drought	0.092
−2.0 ≤ SPI < −1.5	Severe drought	0.044
SPI < −2.0	Extreme drought	0.023

Table 2
Comparative results for the five indices calculated for the periods p1 (1961–1990) and p2 (1981–2010). The numbers express the number of stations belonging to each class.

Index calculated	Class		
	p1 > p2	p2 > p1	p1 = p2
R40mm	25	22	1
R50mm	15	30	3
R90p	9	39	0
R95p	6	42	0
R99p	7	41	0

Table 3
Extreme wet SPI values for the two 30-year periods (1961–1990 and 1981–2010).

Extreme wet index (SPI > 2.0)	Period	
	1961–1990	1981–2010
SPI-3	271	323
SPI-6	250	262
SPI-12	280	261
SPI-24	167	363

study, the number of days with values over 40 mm and 50 mm were calculated for both periods mentioned above (i.e., p1 and p2), with the aim to quantify the differences in the occurrence of extreme rainfall between the aforementioned periods. Furthermore, the percentage of days with an amount greater than the 90th, 95th and 99th percentiles is calculated in order to identify increase or decrease in the extreme events, after comparing the two periods of study.

Kostopoulou and Jones (2005) studied climate extremes by calculating a number of climate indices emphasising on precipitation and temperature with meteorological data provided by ten countries covering the European side of the eastern Mediterranean Sea, for the period 1958–2000. They found that the eastern Mediterranean region (Balkan Peninsula, western Turkey and Cyprus) reveals, generally, negative trends, indicating tendencies towards a drying climate over time, especially, at the southern coastal and island stations, which present large positive and significant trends in the maximum number of the consecutive dry days (CDD) index.

Giannakopoulos et al. (2010) used a high resolution Regional Climate Model (RCM) to examine future climate changes and variations in precipitation over Cyprus. Two future periods were studied, 2021–2050 and 2071–2100, while results were compared from the recent past (1961–1990) for both mean and extreme parameters. They concluded that a drop in rainfall amounts is foreseen for future simulations. The sharpest decrease was evident seasonally for the 2071–2100 simulation (decrease in winter accompanied with decrease in autumn), whereas, for the 2021–2050 simulation, rainfall showed a decrease in winter, but an increase in autumn. An increase in the dry period with precipitation below 1 mm of about 15 days for 2021–2050 and of about 15 days to 1 month for 2071–2100 was also indicated.

In this study, the focus is over the island of Cyprus, for two 30-year periods, namely 1961–1990 and 1981–2010. Indices regarding extreme daily rainfall together with the SPI, that uses monthly amounts of precipitation, are analyzed and examined.

Section 2 focuses on the presentation of the data used in this study and the methodology adopted. The results are resented and discussed in Section 3. Finally, some concluding remarks are given in Section 4.

Table 4
Extreme dry SPI values for the two 30-year periods (1961–1990 and 1981–2010).

Extreme drought index (SPI < −2.0)	Period	
	1961–1990	1981–2010
SPI-3	412	362
SPI-6	556	471
SPI-12	527	489
SPI-24	747	388

2. Data – methodology

The Cyprus Department of Meteorology operates a very reliable and well-distributed network of meteorological stations which complies with the World Meteorological Organization's requirements. This network adequately covers the island providing data for almost a century, with nearly 150 stations, providing precipitation data daily. The stations that were used for this study were selected on the basis of a continuous daily record for a 30-year period, meaning that the stations chosen had full records of thirty years for both periods compared (e.g., 1961–1990, hereafter denoted by p1 and 1981–2010, hereafter denoted by p2). For this purpose, due to data gaps in the archives of some gauge station records, the total number of stations used in this analysis was narrowed to only 48. However, spatial distribution criteria were also taken into consideration so that the ensemble of the 48 stations includes coastal, inland and mountainous sites. The stations used in the present study are displayed in Fig. 1.

The above two periods (namely, 1961–1990 and 1981–2010) were selected on purpose. The World Meteorological Organization has recently endorsed an updated definition of the climatological standard normal and its calculation (see World Meteorological Organization, 2011; Chapter 4, item 4.8, updated 19 January 2016). More specifically, it was decided that the climatological standard normal be calculated every 10 years at the start of every new decade to serve as the updated official climatological standard normal. This applies to the most recent 30-year period, with 1981–2010 being the new current standard; However, for the specific purpose of long-term climate change monitoring, the period 1961–1990 is retained as a reference period in perpetuity or until such time as a compelling scientific case to change it arises.

The results presented in this paper are based on two different kinds of indices. First, the indices using daily precipitation amounts are shown, followed by the SPI results, where monthly precipitation was used. In a previous related study, a number of precipitation climatic indices were calculated, referring to the same two 30-year periods (1961–1990 and 1981–2010) for Cyprus (Katsanos et al., 2017). The aforementioned study's findings imply that although the length of the period of rainy days seems to be shortened, an increase of extreme precipitation (in absolute values) is evident for the 1981–2010 period.

In the present study, the daily precipitation indices used for the study of extreme precipitation events are denoted as R90p, R95p, R99p, representing the threshold for days with precipitation amounts above the 90th, 95th and 99th percentile, respectively; also, R40mm and R50mm denote the number of days with precipitation amount above 40 mm and 50 mm, respectively.

As shown by Katsanos et al. (2016), for Cyprus as a whole, for moderately wet days, the corresponding value for R90p hardly exceeds 3 mm/day; for the very wet days, R95p ranges between 3.5 and 10.5 mm/day, while for the extremely wet days, R99p obtains values between 17 and 64 mm/day.

Drought is considered one of the most important natural hazards related to climate and one of the most widely accepted indices used to characterize is the SPI. SPI is characterized as a tool that can be used on an operational basis as a regional or national drought watch system (WMO, 2012). Standardized precipitation is the difference of precipitation from the mean for a period of time divided by the standard deviation. McKee et al. (1993) originally calculated the SPI for 3–, 6–, 12–, 24–, and 48–month time scales. SPI is used to determine the severity and rarity of a drought event and can be calculated for various periods ranging from 1-month total of precipitation to 48-month total of precipitation. In this study, four periods were chosen: 3, 6, 12 and 24 months. The 3-month SPI can be used for seasonal trends in precipitation, the 6-month for medium-term trends and the 12-month and 24-month for long-term trends. SPI is a tool that due to its standardization provides independence from the geographical position and has been used before in Cyprus to study the severe drought of 2007–2008 (Michaelides and Pashiardis, 2008). The formula used to calculate the SPI is rather simple:

$$\mathrm{SPI} = \frac{(x_i - x)}{s}; \quad (1)$$

where x_i is the monthly rainfall amount, x the mean and s the standard deviation of rainfall calculated from the whole time-series (see Livada and Assimakopoulos, 2007).

Positive SPI values indicate greater than the median precipitation and negative values indicate less than the median precipitation. In this study, SPI is calculated using NCL scripting language, after converting the data to monthly amounts of precipitation. Table 1 presents the classification of drought (from extremely wet to extreme drought), based on the values of the calculated SPI, together with the probability of occurrence (http://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_spi.pdf).

3. Results – discussion

In this section, the results of this research are presented and discussed. The results for the daily precipitation indices are presented first, followed by the results for the SPI.

Table 2 presents the comparison of the two periods of study regarding the calculation of the above five precipitation indices, in terms of number of stations that have a positive trend (p2 > p1), a negative trend (p1 > p2) or no trend (p1 = p2). It can be seen that there is a positive trend for the majority of the stations used, regarding the indices based on the exceedance of percentiles, implying an increase in the occurrence of extremely precipitation values. This is also evident in the other two indices, since for the 40 mm threshold the negative trend slightly surpasses the positive, while for the 50 mm the positive doubles the negative trend.

Fig. 1 presents the trends (positive/negative) in the differences between the two periods, regarding the indices that use daily amounts of precipitation. The difference is defined as p2-p1 and is calculated for each of the 48 stations employed in the present study (their locations showed in the plots). Therefore, positive implies that there is an increase in the specific index in period p2 compared to period p1 for the station (shown as red dots in the figure), while negative means that there is a decrease for the station (shown as blue dots in the figure) for a specific index.

On the one hand, the majority of the stations exhibiting a decrease in the number of days with precipitation exceeding 40 and 50 mm in period p2, seem to be located either on or in proximity and around the central Troodos massif. However, a topographical influence is not clearly evident regarding this group of stations, because stations with similar topographical characteristics exhibit an increase in the corresponding number of days. On the other hand, most of the stations that are situated in low land parts of the country seem to exhibit an increase in the number of days exceeding the above two thresholds, with some exceptions too. This can lead to the conclusion that, in the most recent period p2, lower lying areas are more prone to the effects of increased number of days with high precipitation, such as flooding and soil erosion (see Alexakis et al., 2014; Panagos et al., 2016), than the more elevated mountainous regions.

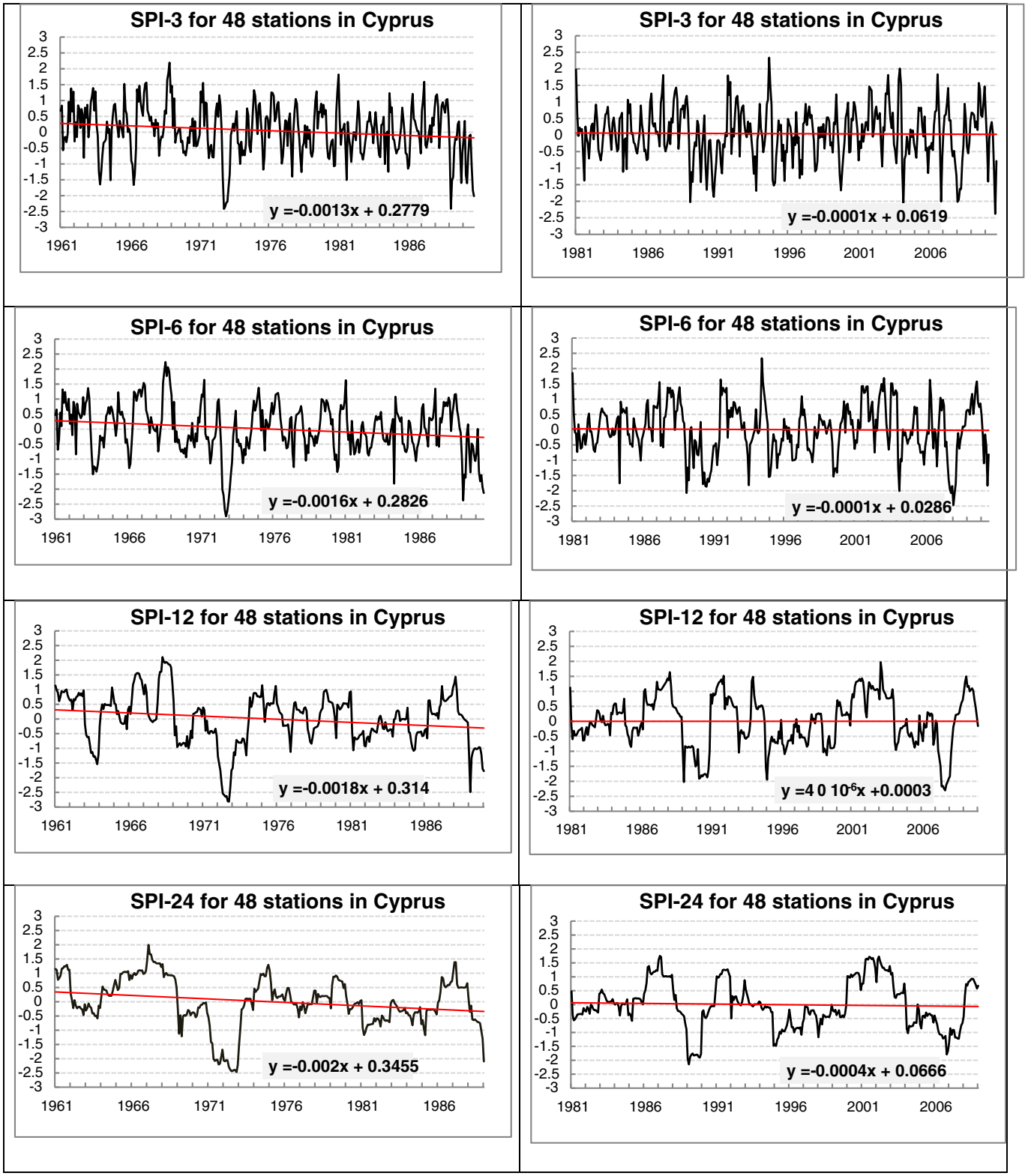
SPI-3 for 48 stations in Cyprus
y =-0.0013x + 0.2779
SPI-3 for 48 stations in Cyprus
y =-0.0001x + 0.0619
SPI-6 for 48 stations in Cyprus
y =-0.0016x + 0.2826
SPI-6 for 48 stations in Cyprus
y =-0.0001x + 0.0286
SPI-12 for 48 stations in Cyprus
y =-0.0018x + 0.314
SPI-12 for 48 stations in Cyprus
y =4 0 10-6x +0.0003
SPI-24 for 48 stations in Cyprus
y =-0.002x + 0.3455
SPI-24 for 48 stations in Cyprus
y =-0.0004x + 0.0666

Fig. 2. Mean SPI values for 48 stations regarding 3, 6, 12 and 24 month periods (from top to bottom) for p1 (left column) and p2 (right column).

Regarding the trends with respect to the percentiles, the majority of the stations used in the study appear to exhibit an increase in period p2 as far as the respective number of days exceeding the corresponding percentile are concerned (also evident from Table 2). Regarding the spatial distribution of the stations with changes in percentiles, it seems that the few stations which exhibit a decrease in p2 are predominantly located in low lying sites. The general view, however, is that in period p2, there is a widespread increase in the number of days exceeding all the percentile thresholds, i.e., there are generally, more moderately, very wet and extremely wet days.

Tables 3 and 4 present the number of times that SPI values surpass the thresholds for extreme wet and extreme drought, for each of the two 30-year periods (1961–1990 and 1981–2010), respectively. With the exception of SPI-12, it is apparent from Table 3, that during the second

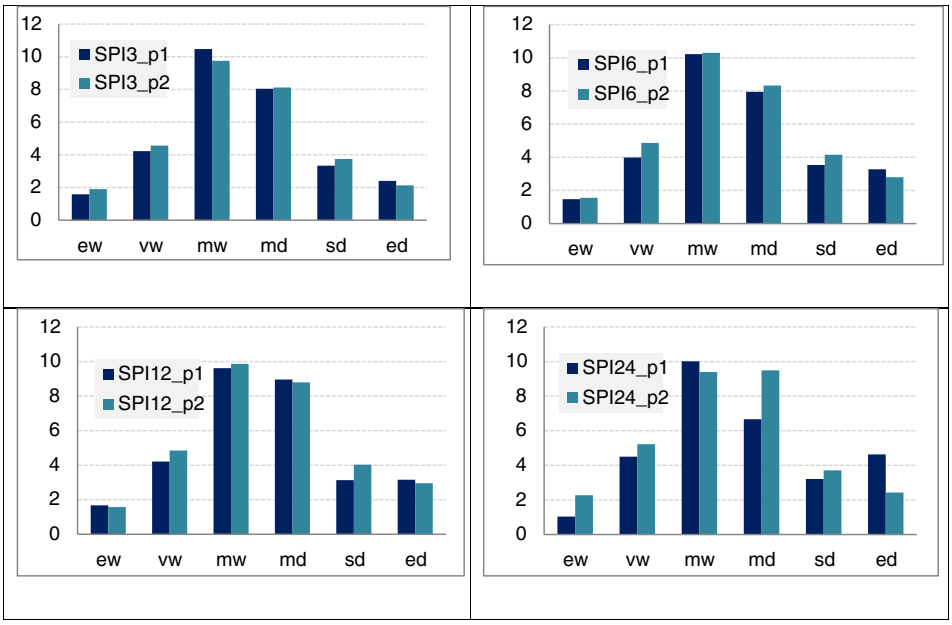

Fig. 3. Frequency distribution of SPI classes for the two periods studied. SPI classes are indicated as extremely wet (ew), very wet (vw), moderate wet (mw), moderate drought (md), severe drought (sd) and extreme drought (ed).

period the extreme wet threshold is more often surpassed. It is also evident from Table 4, that the first period has extreme dry months more often than the second period, for all the four SPI categories. From the above, it can be said that, in general, the second period is characterized by more extreme wet and less extreme drought months.

Fig. 2 presents the time evolution of SPI values for all month periods chosen (3, 6, 12 and 24) and for both the selected 30-year periods, in order to compare them. The most significant droughts recorded during both periods (Pashiardis and Michaelides, 2008) are identified well in the figures. On the one hand, the plots referring to the 1961–1990 period (left column) show a clear decrease of the values, as indicated by the fitted trend line and the corresponding equations, and it is evident for all SPI classes. This implies a tendency for an increase in the severity of dry periods in this first period. On the other hand, the plots for the 1981–2010 period (right column) show a more stable situation, since for all SPI classes there is either a slight decrease or no trend at all.

Based on the graphs for SPI-12, it is evident that in the period p1 three very dry periods (1963–1964, 1971–1974, 1989–1990) are identified with SPI values varying between -1.5 and -3. On the contrary, in the period p2, the dry periods are more often evident; although not that intensive, they last longer (1989–1991, 1995–1999, 2007–2009).

Fig. 3 presents the frequency distribution of the SPI classes for both time periods, having excluded the “near normal” class, since it was around 70% and made it difficult to identify the differences for the other classes. For SPI-3, p2 surpasses p1 for extreme wet (ew), very wet (vw) and severe drought (sd) classes, while p1 has higher percentages in moderate wet (mw) and extreme drought (ed) classes. For SPI-6, p2 has higher values for vw, md and sd and p1 for ed. Regarding SPI-12, p2 has higher percentage values for vw, mv and sd while p1 has higher values for the rest of the classes, however, without a notable difference. Finally, for SPI-24, p2 has higher values for ew (almost double), vw, md and sd, while p1 surpasses for mw and ed (almost double).

4. Conclusions

In this study, several indices were employed in order to investigate the differences in the occurrence of extreme wet and dry events in Cyprus, between two 30-year periods. The first period 1961–1990 is used as a reference and is compared with the more recent period 1981–2010.

Regarding extreme precipitation indices, it seems that the most recent period p2 is characterized by a more often incidence of heavy daily rainfall, since in the indices in which 24-h amounts were used, p2 outscored p1 in 4 of 5 of cases. According to the results, days with > 50 mm occur more often during p2 for 30 stations, while this threshold is surpassed more frequently only for 15 stations during p1. Also, for the 40 mm threshold the values are 22 and 25 stations, respectively. Moreover, during p2, > 80% of the 48 stations that were studied have increased their percentage of days with higher precipitation than the 90th, 95th and 99th percentiles.

Looking for any spatial patterns associated with these finding we concluded that there is no clear topographical influence; however, it seems that concerning the period p2, lower lying areas are more prone to the effects of increased number of days with high precipitation than the more elevated mountainous regions, while there is a widespread increase in the number of days exceeding all the percentile thresholds.

Regarding SPI and focusing on monthly precipitation, it seems that p1 has a trend for more severe droughts in all SPI categories, from 3-month to 24-month. On the contrary, there is lack of such a trend in p2. Furthermore, values of extreme precipitation are more often during p2, while values of extreme drought occur more frequently during p1.

It must be noted that the two periods, p1 and p2 defined by the World Meteorological Organization, as explained in Section 2, and adopted in this study, are not mutually exclusive because they have a common overlapping period, that of 1981–1990. Hence, the findings of the present analysis are to some extend based on a shared period of ten years; however, since the introduction of the updated definition of the climatological standard normal almost one year ago, the 1981–2010 period is the first and more recent 30-year period considered as being the new current standard. The findings in the present study are the first to be published for Cyprus for this new current standard period and are also compared with findings for the long-established reference period 1961–1990. From the results and the discussion in this paper, it is apparent that conclusions that were drawn on the basis of the traditionally used reference period may have to be altered when a new climatological standard normal period is adopted.

Future work includes the extension of this study by incorporating satellite precipitation retrievals also, in an effort to better understand any spatial patterns of precipitation extremes in Cyprus.

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